I. Utilizing Glycerol in Swine and Poultry Diets: I. Feed Manufacturing Considerations and II. Nutritional Consequences

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II. Objectives of research project:

1) Quantify the physical and chemical consistencies of glycerol sourced from multiple biodiesel production facilities.

2) Quantify the storage characteristics of glycerol under varying environmental conditions.

3) Evaluate the effects of glycerol on feed dustiness and feed flowability.

4) Evaluate the effects of glycerol on the pelleting process and pellet quality.

III. Project status regarding stated time
All projects are completed.

IV. Project modifications
The original proposal was not modified.

V. Results

Objective One – Quantify the physical and chemical consistencies of glycerol sourced from multiple biodiesel production facilities

A survey of the bio-diesel industry was conducted to quantify the physical and chemical properties of crude glycerol originating from: 1) individual biodiesel production facilities over time; 2) across multiple biodiesel production facilities. Thirteen U.S. biodiesel production facilities were solicited for this survey. At each facility, representative samples of the feedstock (i.e. animal fat, soybean oil, corn oil) and resultant glycerol were collected and characterized for color, viscosity, particulate matter, pH, moisture using the Karl Fisher Method, methane, fat content, and gross energy. Each assay was conducted in duplicate.

The chemical and physical properties of the feedstock and glycerol samples assayed are presented in Table 1. There was considerable variation between samples, particularly when comparing glycerol from the different feedstocks (vegetable vs. animal). As expected, the gross energy content was higher in the starting material compared to the glycerol, as the fatty acids are removed during the production of biodiesel. There was more residual fat remaining in the glycerol from animal fat, and the residual methanol was consistently higher compared to that from vegetable oil. As both fat content and particulate matter increased, clarity and viscosity decreased.

Table 1. Composition of glycerol obtained from commercial bio-diesel production facilities

	Vegetable		Animal	
Variable	Feedstock	Glycerol	Feedstock	Glycerol
Dry Matter, %	100 (± 0.03)	90.3 (± 1.05)	99.5 (± 0.33)	85.0 (± 7.1)
Fat, %	93 (± 1.27)	0.387 (± 0.07)	94.5 (± 0.82)	15 (± 7.5)
pH	5.9 (± 0.29)	6.53 (± 0.23)	7.04 (± 1.07)	8.47 (± 0.94)
Methanol, ppm	0.0 (± 0)	8.99 (± 4.1)	40.3 (± 29.3)	470 (± 232)
Particulate matter, ppm	6.6 (± 5.3)	0.9 (± 0.65)	6.8 (± 4.6)	8.4 (± 7.7)
Viscosity, cSt/s	79 (± 49.2)	82 (± 19.3)	82 (± 43.0)	38 (± 15)
Gross Energy, BTU/lb	15,757 (± 80.5)	6,005 (± 109)	15,791 (± 100)	7,482 (± 1,005)
Color, s.u.	7.5 (± 2.2)	3.5 (± 0.9)	11 (± 1.68)	11 (± 1.9)

Objective Two – Quantify the storage characteristics of glycerol under varying environmental conditions

An experiment was conducted to evaluate the storability of glycerol under summer and winter conditions. Twelve 1.5 L plastic containers were filled with crude glycerol, and stainless steel or ferrous metal was submerged in each of the containers. The containers were place environmental chambers set to either winter conditions (23^{o}C and 50% relative humidity) or summer conditions (60^{o}C and 5% relative humidity). Visual observations were recorded weekly over a period of two months.

Overall, there was no notable corrosion during the two month experiment for either metal type under the two environmental conditions. There was a slight discoloration observed on the ferrous metal stored under summer conditions (Figure 1), but no pitting or sign of corrosion was noted. No changes were observed in the stainless steel under either environment condition.

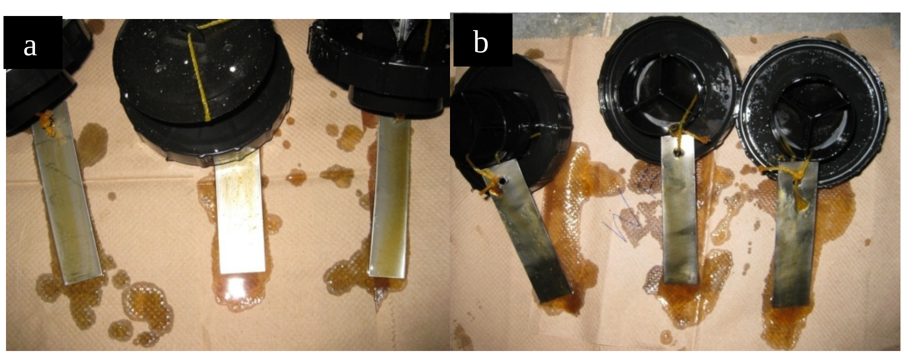

Figure 1. The effects of glycerol on stainless steel (a) and ferrous metal (b) after two months of summer conditions

Objective Three – Evaluate the effects of glycerol on feed dustiness and feed flowability

Two experiments were conducted to determine the effect of added glycerol or a 50:50 soy oil/glycerol blend on the flowability characteristics of ground corn or ground corn and 15 or 30% spray-dried whey. Experiments were conducted using corn ground by either a full circle, tear drop hammermill or a three-high roller mill at the Kansas State University Grain Science Feed Mill. Flowability was determined by measuring angle of repose. In Exp. 1 we evaluated the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of ground corn. Samples were ground through a roller mill (RM) or hammermill (HM). Particle size mean and standard deviations, respectively, of the ground corn were 645 microns and 1.97 for the roller mill and 674 microns and 2.31 for the hammer mill. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn at 0, 2, 4, 6, or 8% for a total of 30 samples (1 RM sample, 1 HM sample, 3 liquid sources, and 5 levels of added liquid). In Exp. 2, we evaluated the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of 85:15 or 70:30 blend of HM ground corn and spray-dried whey. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground corn and spray-dried whey based diets at 0, 4, or 8% for a total of 18 samples (1 HM sample, 2 levels of added whey, 3 liquid sources, and 3 levels of added liquid). Angle of repose was then measured, and replicated 4 times on each sample. In Exp. 1 there was a three way interaction (P<0.05) between mill type, liquid source, and percent liquid added. Roller mill ground grain had a decreased the angle of repose (better flow ability) compared to HM ground grain. The addition of soy oil increased angle of repose, decreasing flow ability. The addition of glycerol or a 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability with HM ground corn. Addition of glycerol did not influence flowability when added to RM corn ground. In Exp. 2 there was a three way interaction (P<0.05) between spray-dried whey level, added liquid source, and percent of liquid added. The addition of glycerol or the 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability. The addition of glycerol decreased angle of repose greater in the 15% spray-dried whey sample compared to the 30% spray-dried whey sample. The addition of soy oil increased angle of repose regardless of spray-dried whey concentration. These data suggest that the addition of glycerol to a meal diet containing HM ground corn will improve flow ability.

Objective Four – Evaluate the effects of glycerol on the pelleting process and pellet quality

a. *Kansas State University Feed Research Center*

Experiments were conducted to evaluate the effects of glycerol on pellet mill performance and feed quality. A corn-soybean meal-based swine grower diet was formulated to contain 0, 3, 6, 9% crude glycerol. Diets were manufactured, pelleted, and data collected at the Kansas State University Grain Science Feed Mill. All diets were steam conditioned to 65, 77 and 88^{o} C by adjusting the steam flow rate and pelleted using a California Pellet Mill (Master Model HD, Series 2000, Crawfordsville, IN.) equipped with a die that had an effective thickness of 31.8 mm and holes 3.96 mm in diameter. Pellets were cooled using a double-pass perforated deck cooler (Wenger Manufacturing, Sabetha, KS). All experimental runs were performed using a warm pellet die. Samples of corn, soybean meal (SBM), diet mash (before conditioning), and pellets were collected for each experimental run.

Pellet mill production data was collected on all diets, and each diet run was replicated by manufacturing a new batch of feed three times. Pellet mill electrical consumption, production rate, hot-pellet temperature, motor load, feeder rate, conditioning rate, and pellet durability were measured. Pelleting efficiency, expressed as kilowatthours per ton (kWh/t), was determined from voltage and amperage meter readings and production rate. Standard and modified pellet durability index (PDI) were evaluated for each experimental run using 500 g of cold pellets (ASAE Standard S269.3; 2003).

The effects of glycerol on pellet mill performance are presented in Table 2. Neither glycerol addition nor conditioning temperature significantly impacted electrical energy usage during pelleting. There was less frictional heating across the face of the pellet die as conditioning temperature increased; however, glycerol did not impact hot pellet temperature. Pellet quality increased linearly as glycerol level and conditioning temperature increased. Though there was not a statistical interaction found between glycerol and conditioning temperature, the pellet mill consistently plugged with diets containing glycerol as the conditioning temperature increased. Out of three attempts, conditioning diets with 9% glycerol to 190°F plugged the pellet mill twice. Though all conditioning temperatures were obtained with diets containing either 3 or 6% glycerol, as conditioning temperature increased, the pellet mill rolls began to slip. Based upon these observations, it appears that the inclusion of glycerol in a diet improves feed quality, however, glycerol inclusion levels are limited to 3% or less due to the negative interaction with steam conditioning.

Table 2 The effects of glycerol on pellet mill performance and feed quality

Treatment		Response Criteria			
Glycerol, %	Cond. Temp. °F	KWH/Ton	Standard PDI[1], %	Modified PDI[1], %	Δ Temp.[2], °F
0		6.63	80	74	4.08
3		6.26	88	85	3.47
6		6.99	94	92	3.62
9		6.78	95	94	4.43
	149	6.74	87	82	7.11
	171	6.68	88	86	4.18
	190	6.59	92	91	0.41
Source of variation		Probability			
Glycerol		0.2995	<.0001	<.0001	0.9451
Linear		0.3389	<.0001	<.0001	0.7947
Quadratic		0.1087	0.2311	0.1926	0.8088
Conditioning Temp.		0.9094	0.0028	0.0013	0.0019
Linear		0.6701	0.0007	0.0003	0.0006
Quadratic		0.9527	0.5377	0.4738	0.7356

b. Don's Farm Supply – Commercial Feed Mill

A study was carried out in a commercial feed manufacturing facility to evaluate the application of glycerol in animal feeds on a large scale. A corn meal-based turkey grower diet was formulated to contain 3% crude glycerol. Diets were manufactured and the data collected at Don's Farm Supply Feed Mill in Newell, Iowa. All diets were steam conditioned in an atmospheric conditioner and pelleted using a 500 HP Bliss Pellet Mill. Samples of pellets were collected and pellet mill amperage was recorded. Both standard and modified pellet durability index (PDI) was determined.

As observed in the pilot pelleting experiment, the addition of glycerol in the diet improved pellet quality slightly. The standard and modified PDI for the control diet was 84 and 82%, respectively, compared to 87 and 83% obtained from the diet with glycerol. The same challenges were faced with the pellet mill plugging as conditioning temperature was increased. Figure 2. shows the amperage on the pellet mill motor over the production run. The amperage surges noted on the chart correspond with the pellet mill beginning to plug and the conditioning temperature exceeding 150° F.

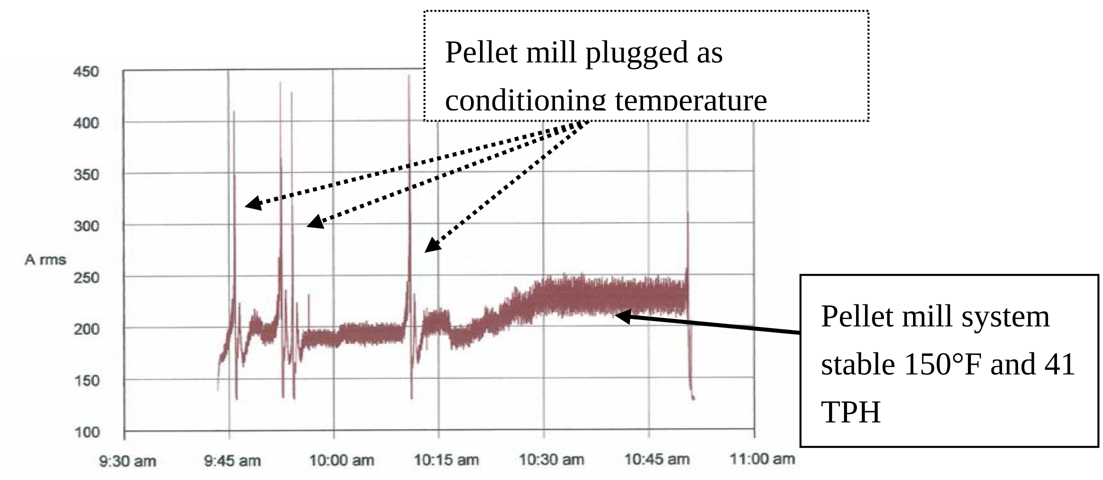

Figure 2. Pellet mill amperage over time during production of a turkey diet with 3% glycerol

The exact reason why glycerol caused the pellet mill rolls to slip is not known at this time. One possible explanation is that the mash moisture content was excessive due to the glycerol and the steam required for conditioning. In general, for every 15°C of temperature rise in the conditioner, 1% moisture is added to the feed mash. If the raw feed ingredients are cold, more steam is required to increase the mash temperature, resulting in elevated mash moisture content. The outside temperature the day of the experiment was -17°F, consequently the mash temperature was excessively cold.

V. Conclusions

Collectively, these experiments address practical issues associated with handling and feeding glycerol, and provide a basis for comparing glycerol with other feed ingredients. As discovered in this project, there is a considerable amount of variability in the composition of glycerol on the market. Consequently, sourcing glycerol may be somewhat of a challenge for feed mills, particularly with respect to obtaining the required maximum methanol concentrations. There did not seem to be any negative aspects regarding the storability of glycerol, however, potential storage problems may require more time before becoming evident. The inclusion of glycerol in diets does have advantages relative to feed quality. The feed tends to flow better with less dust generation. Additionally, pellet quality increased with the use of glycerol. A disadvantage observed with the addition of glycerol, is the limited condition temperatures obtained. However, this may be a result of the temperature and moisture content of the feed ingredients used in these studies.